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Route 1 Sec. 3

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Fig. 13. The Slump Test

Note the frustum of a cone 4 in. in diameter at the top, 8 in. at the bottom, and 12 in. high, used for making this test.

Note

The papers presented at the recent Convention of the New Jersey Highway Association, and the discussions following them, are such a valuable contribution to the progress of road-building that it has been decided to publish them in full with as many as possible of the charts and illustrations used. (It has not been possible to include all of these, however, so there are occasional references in the text, to photographs and charts which have not been reproduced).

Our aim is to publish one or two of the Convention papers, with the discussion thereon, each month. We suggest that these be carefully filed, so that the reader may keep the complete set, which will make a very valuable addition to his road-building library.

This month we are printing "Merits of Fine Gravel As Coarse Aggregate in Concrete for Roads", by J. M. Braly; and the discussion thereon at the convention; also "Recent Developments in Concrete", by H. C. Boyden, of the Portland Cement Association. Next month there will be published "Highways", by Hon. James H. MacDonald, Former State Highway Commissioner of Connecticut; and also "Precautions Necessary for the Proper Application of Glutrin to Gravel Roads", by Maurice R. Young, Contractor.

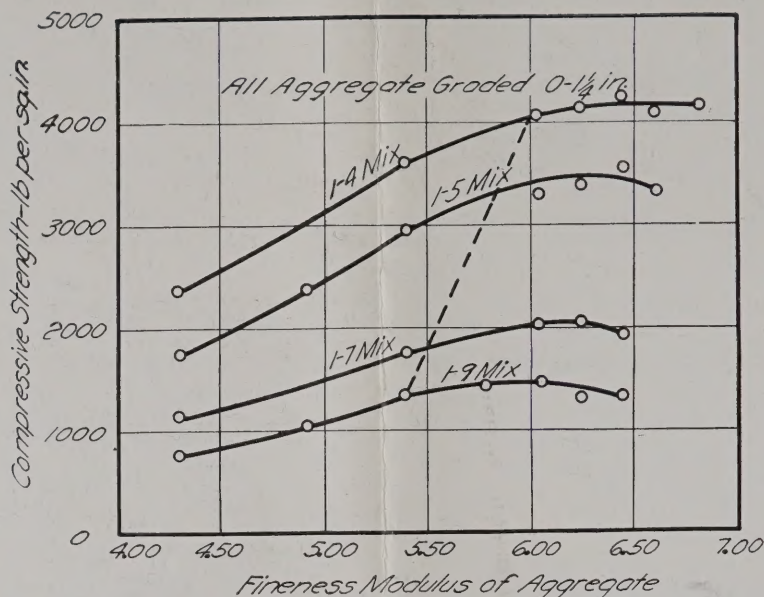


Fig. 1. Relation Between Fineness Modulus of Aggregate and Strength of Concrete.

Note that strength increases as fineness modulus increases up to a certain point, beyond which point the strength falls off, due to the fact that the aggregate becomes too coarse for the amount of cement.

Notes on Recent Developments in Concrete

By H. C. Boyden, Portland Cement Association, Chicago

It is possible that some of the points to be brought out in this paper are more or less familiar to some of those present, through the reading of publications on the subject and the discussion of them in the technical press. There are many, however, to whom the facts will be new and of interest and the others may have questions they would like to have answered. If these questions are not answered in this paper, the Portland Cement Association will be glad to send further information.

The art of making concrete is an old one, but it is only in recent years that serious large scale investigations of its structure and the real effect of various combinations of the ingredients, have been undertaken.

In 1914 the Structural Materials Research Laboratory was established at Lewis Institute, Chicago, with Professor Duff A. Abrams at its head. The establishment of this laboratory was made possible through the co-operation of the Portland Cement Association and the Lewis Institute. This laboratory is a striking example of cooperation between an engineering college and a manufacturing industry of international scope.

There are only two ideas governing the policy of this laboratory: the first is, that the real facts regarding concrete and its ingredients shall be found out, with a liberal policy regarding the time required and the expense involved; the second is, that whatever the conclusions may be, they shall be given to the engineering profession for the improvement of the art of making concrete.

These investigations are still being carried on, but many points of vital importance have already been established. As an example, these data warrant the use of considerably higher unit stresses than those in common use today, with a consequent possible reduction in section. Conclusions have also been reached that will enable excellent results to be obtained with aggregates heretofore condemned, and also to increase greatly the ability of concrete to resist wear.

These conclusions and many others, are all based on tests running into the thousands and covering long periods of time. Incidentally, the laboratory is equipped for and is making close to 75,000 tests a year, so that there is no

lack of facilities for carrying out investigations in the most thorough manner.

General

The study of concrete may be conveniently divided into three phases:

1. The study of the characteristics of the ingredients.
2. The study of the effect of making various combinations of these ingredients.
3. The study of the effect of the various manipulations of the ingredients in making and curing concrete.

This paper will touch on only those investigations that have brought out essential changes in previous ideas of the subject or that have confirmed those ideas beyond a doubt.

It has been the custom to speak of concrete as having three ingredients, cement, fine aggregate and coarse aggregate. The laboratory studies have shown the desirability of classifying the ingredients as cement, aggregate and water, or if it is still desired to maintain the purely arbitrary division of the aggregate into fine and coarse, to add the fourth ingredient, water.

Although cement is one of the most important ingredients of concrete, it requires probably the least discussion, as all the standard brands of Portland Cement on the market today conform to generally accepted specifications and laboratory investigations have brought out no essential need for changes in these specifications.

As stated above the aggregate has always been divided into two parts, sand, and crushed stone or pebbles. The line of division, purely an arbitrary one, is the quarter-inch screen, the portion passing through this screen being classified as fine aggregate or sand, and the portion retained on this screen being called the coarse aggregate. There is no particular advantage gained by this division but it would be much better to consider the aggregate as a whole, with a proper graduation of the various sizes from the largest to the smallest. It is not intended by this, however, to recommend the use of bank run or crusher run aggregate, as under no conditions should they be used without separating the sizes and recombining in the proper proportions.

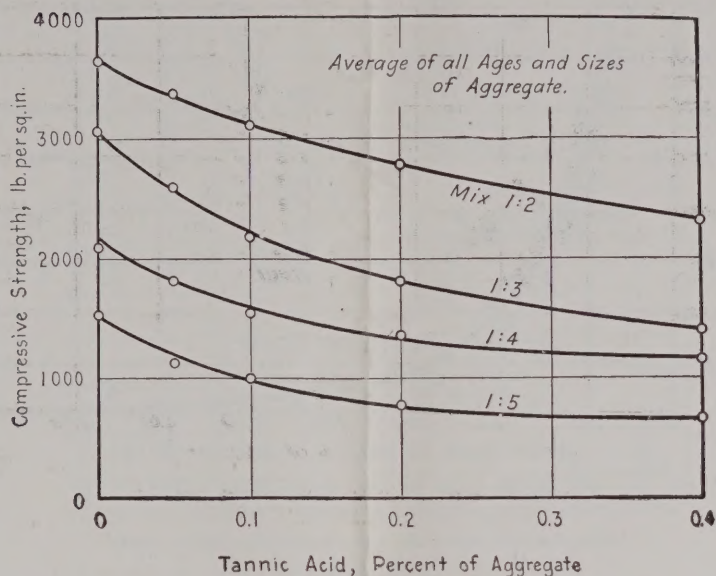


Fig. 2. Effect of Tannic Acid (Vegetable Matter) Upon the Compressive Strength of Concrete.

Note that one-tenth of one per cent of vegetable matter reduces the strength of concrete as much as 30%

However, until such time as this method of considering the aggregate shall have become of general practice we will consider it as being divided into two parts by the $\frac{1}{4}$ inch or No. 4 screen, and will so discuss it.

Fine Aggregate

It is customary to specify that the fine aggregates shall be clean, sharp and not too fine. It would be better to omit the word "sharp", because rounded particles find their way into place more readily than do sharp ones, and require less water to produce a workable mixture. It is this lowering of the relative quantity of water used that causes the greater compressive strength found in concrete made with smooth, rounded sand. It would be well to insert the word "hard" because that quality is very desirable.

The laboratory studies have brought out two important facts regarding sands. One of these is the great importance of being sure that the material is clean, not only in appearance but in fact. Very often sand which appears to the eye to be clean, contains enough humus or vegetable matter to reduce the strength very considerably.

As an illustration, a clean sand gave a compressive strength at 28 days of 1,900 pounds. This same sand with one-tenth of one per cent of tannic acid added, gave a strength of only 1,400 pounds; in other words, one thousandth part of organic impurities in terms of the weight of the sand reduced the strength of the concrete over 25 per cent. In the investigation of the effect of organic impurities many natural sands were used, but as it was not feasible to secure sands containing a wide variation of organic impurities, tannic acid was used as a substitute for the purpose of making further tests. It was felt that the effect produced by such a material would probably be a measure of the effect produced by other organic impurities which might be present in natural sand.

How can these organic impurities be detected if they cannot be seen by ordinary inspection? By using the colorimetric test for organic impurities which was devised at the laboratory. This test consists of digesting a representative sample of the sand in a dilute solution of sodium hydroxide (caustic soda = NaOH) and observing the resulting color of the liquid.

All that is needed is a 12 oz. prescription bottle and a little 3 per cent. solution of caustic soda or sodium hydroxide, both obtainable at any drug store. Put in about $4\frac{1}{2}$ ounces of the sand to be tested, fill up to the 7 ounce mark, after shaking, with the solution of caustic soda, let it stand for 24 hours and observe the liquid on top. If this liquid is clear or light straw colored use the sand; if it runs into the brown color and especially dark brown, reject the sand or wash it thoroughly before using.

The second fact brought out by the laboratory studies is that fine sand behaves exactly the same as coarse sand except in one particular. In order to produce a plastic, workable mixture with fine sand it is necessary to use more water than with a coarse sand. It is the excess of water that reduces the strength of the concrete. In other words if concrete could be mixed with the same quantity of water regardless of the grading of the sand, and a plastic mix obtained in both cases, the same strength would be secured in the concrete.

Coarse Aggregate

When studying the characteristics of coarse aggregate one conclusion has been brought out very sharply; namely, that the hardness of the aggregate is a secondary consideration, as compared with other factors, in developing high crushing strength in concrete, and of less importance than ordinarily supposed in developing ability to withstand abrasion. This was very clearly shown in comparative tests made of burnt shale for use in building concrete ships. Samples made with this aggregate compared very favorably with those made with a much harder aggregate. A stone must be very friable indeed if it is not strong enough when properly combined in concrete, to more than maintain the load likely to be carried by the concrete.

The reason for the high compressive strength often secured where a light, soft aggregate is used, is because the porosity of the aggregate reduces the quantity of water available in the mixture. Here again the relative quantity of the mixing water is the governing factor.

For road surfaces, however, another quality is needed in concrete, namely, resistance to wear or abrasion, and to obtain this the stone must not be too soft. It is not advisable to use a stone with a French coefficient of less than 7 although pavements have given excellent results when made with stone having a coefficient as low as 6.

It is not intended in calling attention to the above results to advise throwing down the bars and allowing the use of any and all stones, irrespective of their hardness or wearing qualities. It is desired, however, to show that many of the safeguards that have been put into specifications in past years are not safeguards at all, and that the effect of following them may be entirely lost through neglect to observe other factors of more vital importance. It is always advisable to use the best materials obtainable; but there have been many cases when the local and easily obtainable material has been rejected, when it could have been used with excellent results, by following proper principles in proportioning and protecting the concrete; oftentimes better results would have been obtained than resulted from the use of imported materials and then neglecting the really important factors in making good concrete.

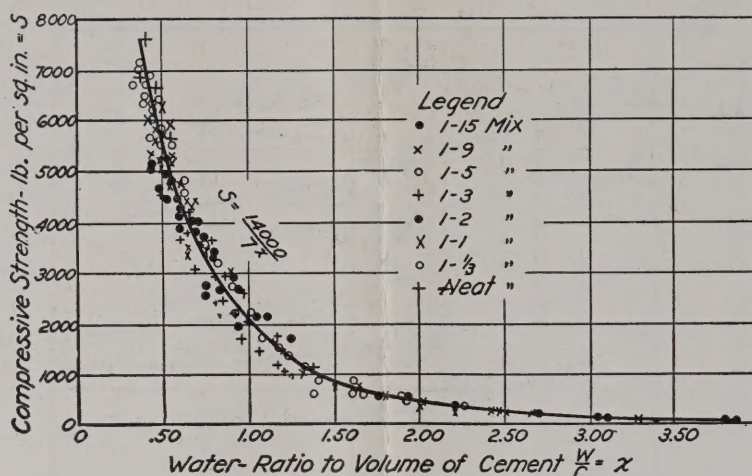


Fig. 3 . Relation Between Water-Ratio and the Compressive Strength of Concrete

Note that the lower the water-ratio the higher is the compressive strength

Water

The remaining ingredient of concrete, water, is in reality of equal importance with the cement in obtaining good concrete, and yet it is often the most carelessly used and most loosely specified of all the ingredients, generally neglected in specifications and frequently not even reported in the published data of concrete tests.

The laboratory has conducted tests of waters sent in from all parts of the country, but definite conclusions have not as yet been published. It is safe to say, however, that waters which are strongly alkaline should not be used, and, owing to the possibility that marsh waters may contain sufficient humus matter to affect seriously the strength of concrete they should be looked upon with suspicion until tested in concrete and found satisfactory. A safe specification is to require that the mixing water shall be potable.

Regarding the temperature of the mixing water, tests have been made, using water ranging in temperature from 32 degrees to 212 degrees F. It was found that the temperature of the mixing water had very little to do with the strength of the concrete. The use of hot water is, however, a valuable aid in removing frost from the aggregate in cold weather, owing to its high specific heat, and may be used without danger of harming the concrete. Hot water tends to hasten the hardening of concrete.

Proportioning

On studying the second phase of concrete making, there have been brought out at the laboratory, new, and in some ways radical changes in the past and present practices of proportioning.

These investigations have brought out the following facts: first, that the present method of designing concrete mixtures by using arbitrary volumes is wrong; second, that there is one single proportion which will give the best results with a mixture of given fine and coarse aggregates; third, that adding to or reducing the amount of cement is of value only as it affects the relative quantity of water required to make a workable plastic mixture; and fourth, above all, that the water-ratio is the most important element of a concrete mix. The water-ratio as used by the laboratory, is the ratio of the volume of the water to the volume of cement in the batch. If 1 cu. ft. of water (7.5 U. S. gals.) is used for each sack of cement, the water-ratio is called 1.00.

The use of more cement in a batch does not produce any beneficial effect except from the fact that a plastic, workable mix can be produced with a lower water-ratio. The reason that a rich mixture gives a higher strength than a leaner one is not that more cement is used, but because the concrete can be mixed with a water-ratio which is relatively lower for the rich mixture than for the lean one. If advantage is not taken of this possibility of reducing the water-ratio the additional cement in the richer mixture is wasted.

Fineness-Modulus

In studying the results of the tests of many samples of various combinations of aggregates it was evident that there must be some relation between the size and grading of the aggregates and the strength of the concrete. In trying to find this relation Professor Abrams struck upon what is called the "fineness modulus" of aggregates and when this was compared with the strengths of the concrete a direct relation was found to exist.

The fineness modulus is a very simple function of the sieve analysis of the aggregate used for any particular concrete. The aggregate is analyzed with a selected set of U. S. standard square mesh sieves, each one of which has a clear opening double the width of the next smaller. The following sizes are used: 100, 50, 30, 16, 8, 4, 3/8 in., 3/4 in., 1 1/2 in. and 3 in. The percentages (by volume or by weight) of the total aggregates coarser than each sieve are added together, the sum of these percentages is divided by 100, and the result is the fineness modulus. The fineness modulus of any combination of the fine and coarse aggregates may be found in exactly the same manner. Aggregates of many different gradings may have the same fineness modulus; or in other words, aggregates of many different gradings may be used and still secure the same compressive strength in the concrete.

It is not claimed that this method of designing concrete mixtures is the only one that will give the desired results but the laboratory tests prove beyond a doubt that there is a direct relation between the compressive strength of concrete and the factor called the "fineness modulus". This is because the fineness modulus reflects the changes in the water-ratio necessary to produce a given plastic condition in concrete. Accepting this as a fact, it is possible to design a concrete mixture that will give a certain desired compressive strength from many different combinations of aggregates.

It is not possible in a paper of this length to go into the details of the use of this factor for the design of concrete mixtures, but they were published in the *Engineering News-Record* of April 17, 1919, and a careful study will enable one to use this factor successfully.

Abrams' Tables of Proportions and Quantities

In order to make these principles more easily available to engineers, architects, contractors and other users of concrete, Professor Abrams has worked out tables of the proportions and quantities required to produce concrete of compressive strength from 1500 to 4000 lbs. per square inch, at 28 days. All the tests for the determination of the factors in these tables were made of concretes of varying consistencies, formed into cylinders 6 in. by 12 in. in size and tested at the end of 28 days.

In conformity with present practice the aggregate is divided in the tables into fine and coarse, and covers combinations of five classes of fine aggregate with eleven classes of coarse aggregate.

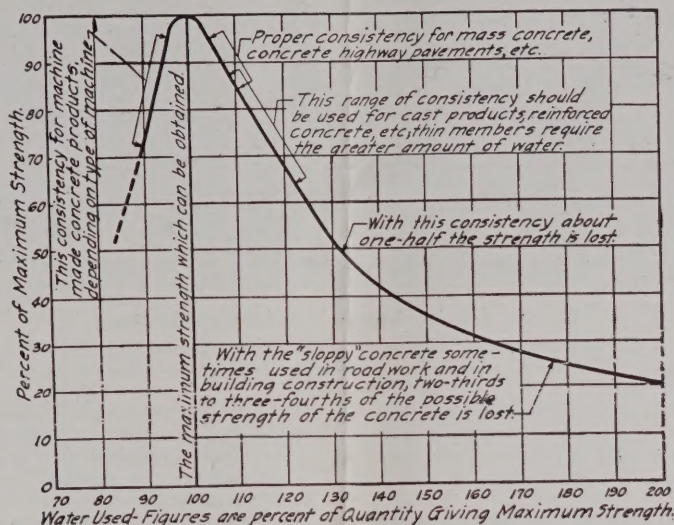


Fig. 4. Effect of Quantity of Mixing Water on the Compressive Strength of Concrete

Note: In general construction, the maximum strength can rarely be obtained, but it is possible to obtain 70% to 90% of the maximum strength without additional expense by watching the water content carefully.

Four different consistencies, as indicated by the slumps of the concrete, are used for each combination so that there are 220 different combinations for each strength or 1320 combinations in all.

The quantities shown in the tables are considerably less than those shown in any previously published table due to the fact that they are absolutely net quantities based on laboratory methods of measurements of the aggregates. For this reason the quantities given should not be used for estimating without the addition of proper allowances for waste and the differences due to the practice of measuring aggregates in a loose condition when making field concrete.

These allowances should vary for each ingredient and also according to the particular method to be employed in handling the work. For general conditions the following percentages to be added to the table quantities are offered as a suggestion: cement 2%, fine aggregate 10% and coarse aggregate 7½%.

Water Content

Upon studying the water content, the most radical change from previous ideas on the design of concrete

mixtures is found. Based upon thousands of tests it has been established that there is a direct connection between the relative quantity of mixing water used and the strength of the concrete and there is probably no other one factor which has so great an effect upon the strength as the water content.

It has been found that the less water used, as long as the mixture is plastic, and the aggregate is not too coarse for the amount of cement used, the stronger will be the concrete. This does not mean that the amount of water can be reduced too far, nor that, in actual construction, it can be reduced to a point that would give the maximum strength shown in laboratory tests. There is another factor that must be taken into account in construction and that is the workability of the mix. In general terms it can be stated that the lowest water-ratio should be used that will give a workable mix.

Within the range of plastic mixtures, the strength falls off very quickly with the addition of a small amount of water; so much so that in a one bag batch the addition of one pint of water more than is necessary to give a workable mix produces the same loss in strength as if two or three pounds of cement had been left out. Do not think from this that a very lean mix with a small quantity

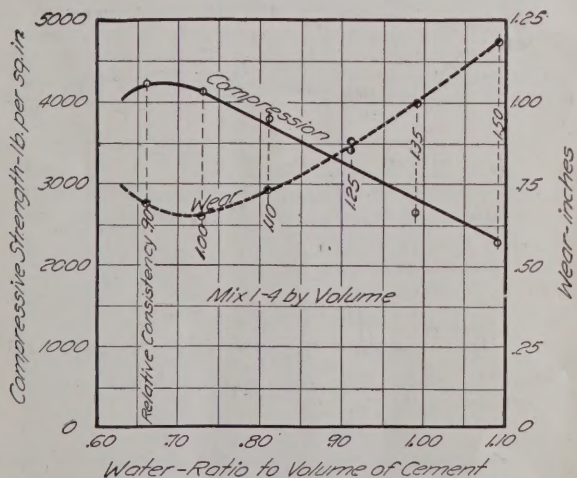


Fig. 5. Relation Between Quantity of Mixing Water, and the Compressive Strength and Resistance to Wear of Concrete

Note that the curves are practically the opposite of each other. In other words, that proper restrictions on quantity of mixing water increase the compressive strength and increase the resistance to wear (that is decrease the wear).

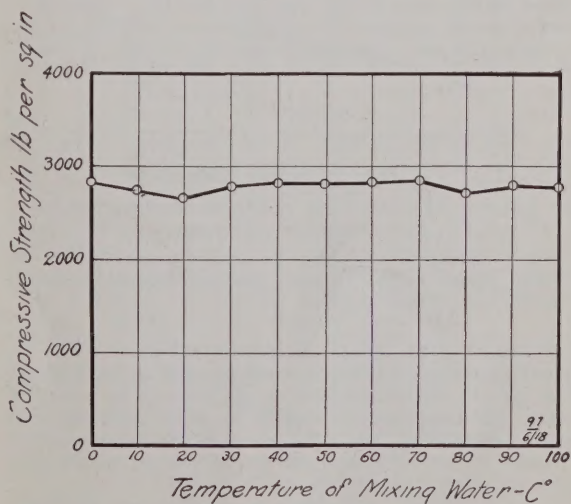


Fig. 6. Effect of Temperature of Mixing Water on Compressive Strength of Concrete

Note that no appreciable effect is produced by changes in temperature of mixing water between 32 and 212 degrees F.

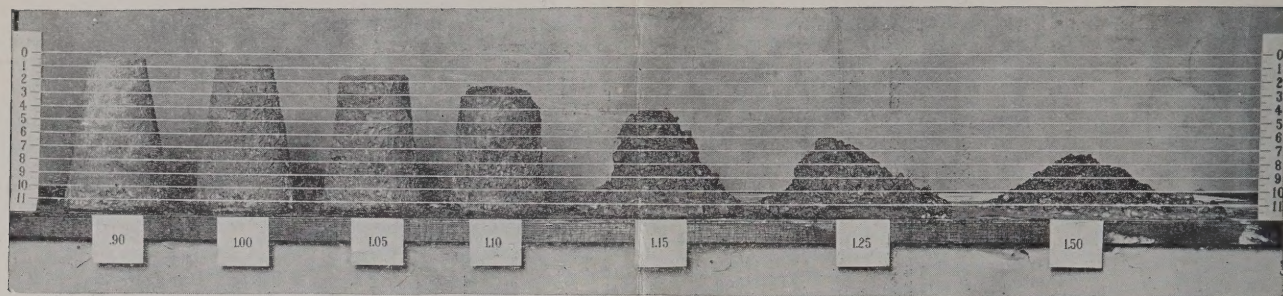


Fig. 14. Relation between Consistency and Slump

Note: Proper slump for roads and pavements from $\frac{1}{2}$ in. to 1 in.; for foundation and mass work from 1 in. to $1\frac{1}{2}$ in.; for concrete containing reinforcing bars from 2 in. to $2\frac{1}{2}$ in.

of water will give as strong a concrete as a rich mix with the same quantity of water. This is not true, because it will require a higher water-ratio to produce a workable mix with the lean mixture, thereby causing a loss in strength.

The proper consistency for concrete will vary according to the use to be made of it. If the concrete is to be used for roads a dryer consistency is permissible than for concrete containing reinforcing bars. The use of mechanical tamping and finishing machines in concrete road construction has made it possible to use the dryer consistency economically, but any method which reduces the water content, such as the use of the light roller, will produce beneficial results.

The very wet sloppy mixtures that are being used in building construction may seem economical from the contractors' point of view but they are certainly extremely wasteful from the designers' and owners' point of view, since in many instances 50 to 60 per cent. of the possible strength of the concrete is being thrown away.

It may not be possible to reduce the amount of the water to the ratio necessary to give the maximum strength, but it certainly can be cut down below the amount commonly used, and the additional strength thus gained will be of

and also because of the varying moisture content of the aggregate. However, a few approximate quantities for different proportions of well graded aggregates up to $1\frac{1}{2}$ in. in size, may be given to form a basis for trial of the particular mixture at hand. 1:2:4 mixture will require from 6 to $6\frac{1}{2}$ gallons of water per sack of cement, a 1:2:3 mix, $5\frac{3}{4}$ to 6 gallons, and a 1:1 $\frac{1}{2}$:3 mix, $\frac{5}{2}$ to 6 gallons.

Slump Test

In order to have a simple method for determining the proper consistency in the field the slump test has been devised. At first a metal cylinder 6 inches in diameter and 12 inches high was used, but now a frustum of a cone 4 in. in diameter at the top and 8 in. at the bottom, and 12 in. high has been adopted as a standard. This cone is filled with the concrete to be tested, which is carefully worked with a pointed metal rod while it is being placed, the form is immediately lifted off, and the settlement or slump measured. The proper slump for a mixture to be used for a concrete road surface is $\frac{1}{2}$ to 1 in.; for mass work, from 1 to $1\frac{1}{2}$ in., and for concrete to be used in structures with reinforcing bars, 2 to $2\frac{1}{2}$ in. In some classes of reinforced concrete work increased plasticity or flowability may be needed. It must only be obtained by

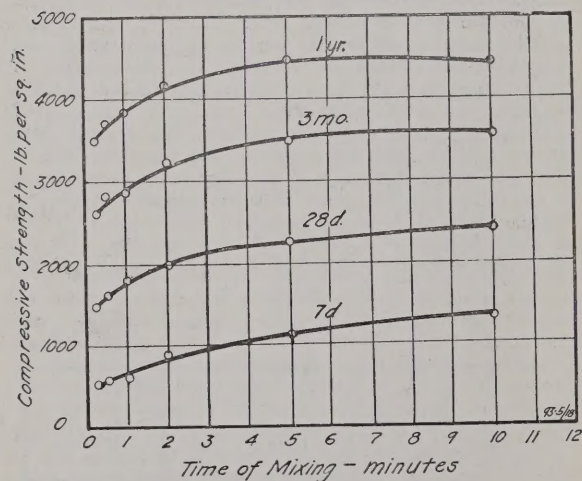


Fig. 7. Effect of Time of Mixing on Compressive Strength of Concrete

Note rapid increase during first minute, slightly less increase during second minute, and slight increase during remainder of time of tests.

advantage in the design of concrete structures. The designing engineer figures on a compressive strength of 650 lbs. per sq. in. and expects to get a factor of safety of three, but does not get it with the sloppy mixture often used. By cutting down the water to the proper ratio, a factor of safety of five or six can be secured, or the present allowable unit stresses can be raised.

The exact amount of water required for any particular mixture of aggregates to obtain the greatest strength in the concrete cannot be given, because of the impossibility of determining what amount will produce a workable mix

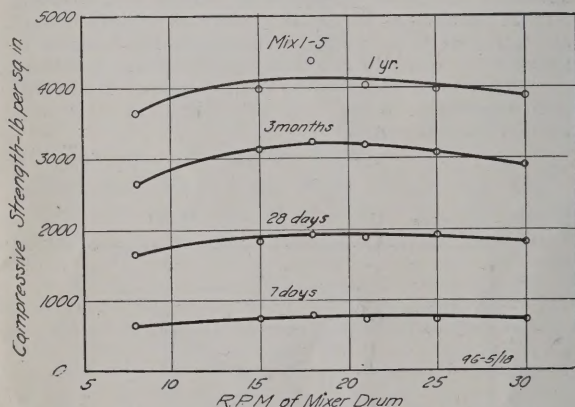


Fig. 8. Effect of Revolutions Per Minute of the Mixer Drum Upon Compressive Strength of Concrete

Note that between 12 and 25 R. P. M., the speed of the mixer drum has practically no effect on the strength of the concrete. Concrete mixed one minute at 12 R. P. M. gave the same strength as that mixed one minute at 25 R. P. M.

adding cement as well as water, in such quantities as to maintain the proper water ratio, otherwise a serious loss in strength will occur.

Manipulation of Ingredients

In considering the final step—the manipulation of the ingredients during the making of the concrete—careful studies have been made of each operation. Included in this phase are the operations of mixing, transporting and placing, and also the curing or protecting of the concrete during the early hardening period, which is one of the most vital operations in the making of good concrete.

The time of mixing is a matter of importance in obtaining good concrete and as this factor largely controls the

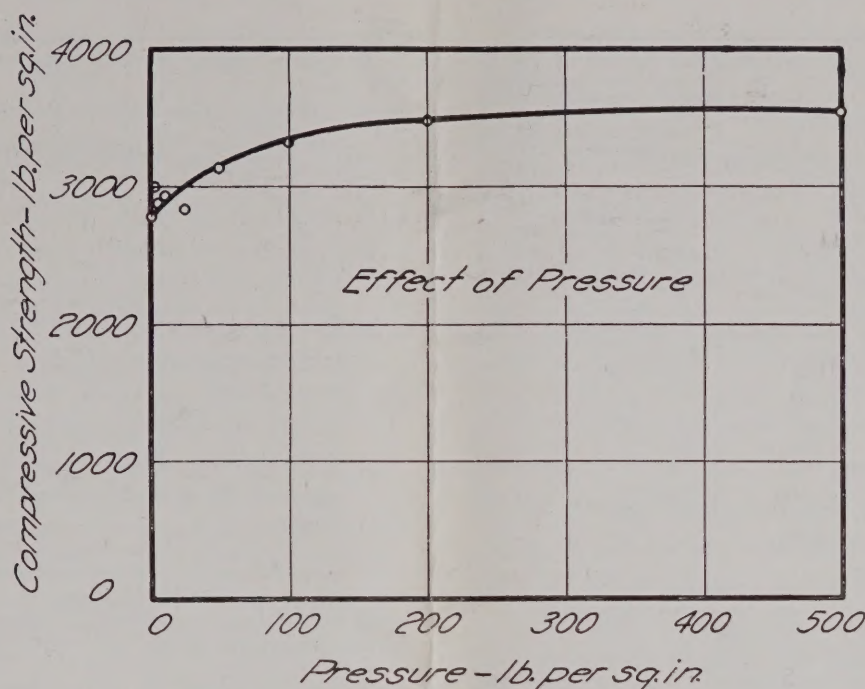


Fig. 9. Effect of Pressure Upon Freshly Moulded Concrete

Note that the compressive strength is increased by pressure. This increase is directly proportional to the amount of water squeezed out, making a reduction of the water-ratio.

output of the mixer, it affects the cost of the concrete. Consequently there is an unfortunate tendency to reduce the time of mixing, a practice which cannot be too severely condemned, because it results in a material loss in the strength of the concrete, and a lack of uniformity. Exhaustive tests made on concrete mixed in a batch mixer from 15 seconds to 10 minutes, show a rapid increase in strength for the first minute, and a slightly smaller increase for the second minute, after which the increase in strength is less pronounced as the time of mixing increases. This shows the necessity of mixing the concrete at least 60 seconds after all the ingredients, including the water, have been placed in the drum of the mixer, and not 20 to 40 seconds only, as is often done in road and street construction. There is no question as to the advisability of using a batch meter on the mixer, provided one can be found that cannot be tampered with, in order to avoid controversy over the time of mixing and to insure a full minute mix. When a mixer is manufactured that will not permit discharge until a certain number of revolutions have been made at a certain speed this problem will have been solved.

The revolutions per minute of the mixer within the limits of 12 to 25 R. P. M. have but little effect on the strength of the concrete, so that a sufficiently wide variation for different machines is permitted. In making tests of the effect of R. P. M. on concrete the total time was one minute in all cases, and all materials, including water, were placed in the drum before the time interval was counted.

The effect of pressure on concrete immediately after moulding is found to be due to the amount of water squeezed out, making a consequent reduction of the water-ratio. Tests were made on concrete of the same proportions, by applying pressure from zero to 500 lb. per sq. in. The water expelled was carefully collected and measured. It was found the strength increased quite materially with the higher pressures and this increased strength was almost directly proportional to the amount of water squeezed out.

It is not surprising to find, then, that the duration of the pressure had no effect whatever on the strength of the concrete. Whether pressure was applied for a few minutes or for several hours the effect produced was exactly the same. It is undoubtedly the squeezing out of the water and consequent reduction of water-ratio that produces the

excellent results when the roller method of finishing concrete roads is used.

The time that can be allowed between the time of mixing and the time of placing has not as yet been made the subject of extensive tests at the laboratory. This knowledge will be of value when considered in conjunction with central mixing plants, which are used with success in many places. The time which may elapse between mixing and placing without injury to the concrete is probably governed to a certain extent by the kind of cement used, by the temperature of the mixed concrete, by the nature of the vehicle and the road over which the mixture is hauled. In Illinois a limit of 40 minutes lapsed time is allowed, but it is generally believed that the economical haul for the job will be the governing factor rather than the fixing of a time limit.

It is possible that some of the present ideas regarding this factor may be changed by the results of a series of laboratory tests, but until such a time it would not be advisable to allow re-tempering of concrete that has been too long in transit, as the addition of water will no doubt result in a reduction in strength.

Protection

The proper protection of concrete during the early hardening period is a detail of construction that is too often overlooked and many times only indifferently carried out. The effect of proper curing conditions upon the ability of the concrete to withstand abrasion has been very strongly brought out by numerous tests in the laboratory. There is probably no factor in the handling of concrete that so affects its wearing ability, as that of providing proper protection while curing or hardening.

It is true that any and all of the factors that tend to produce strength in concrete also tend to increase its wearing qualities; nevertheless all of our tests show that other factors being the same, the concrete which is properly protected will show much more compressive strength and much less wear than that which has been allowed to dry out too quickly. As an illustration of this, at the end of four months the compressive strength of a concrete of 1.25 consistency was about 1,700 lbs. per sq. in. when it was allowed to dry out in the air unprotected, while exactly the same concrete stored in damp sand for the first 21 days

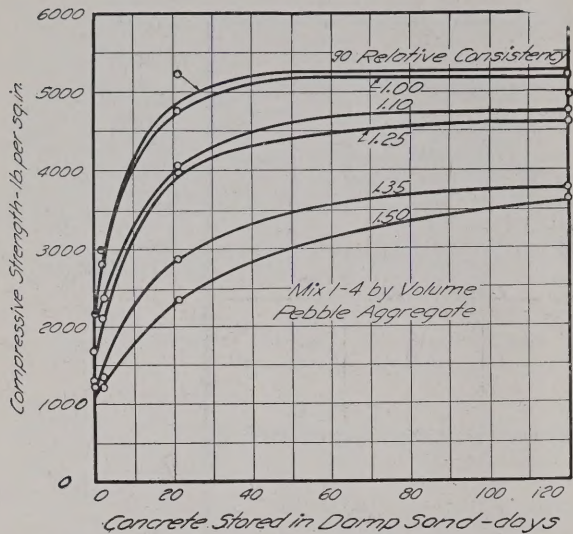


Fig. 10. Effect of Proper Protection During the Early Hardening Period Upon the Compressive Strength of Concrete

Note that the greater effect is on the drier consistencies, but that even the wetter consistencies are more than doubled in strength by proper curing conditions during first 21 days.

gave a compressive strength of about 4,000 lbs. per sq. in., and a correspondingly less wear in the rattler test.

One of the principal causes of the poor wearing resistance that is sometimes found in concrete floors is due to the practice of allowing them to dry out without proper protection during the hardening period. Concrete floors under roof should be covered and kept moist just as outside roads and pavements are protected. Why throw away one-half of the life of concrete floors by failing to observe this rule and holding back from using them for so short a period?

The essential requirements for proper hardening are

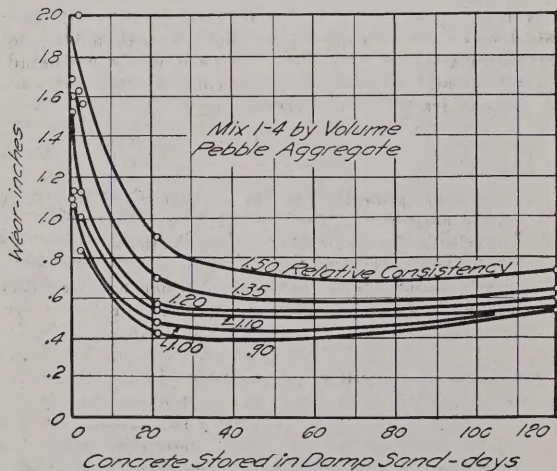


Fig. 11. Effect of Proper Protection During the Early Hardening Period Upon the Resistance to Wear of Concrete

Note that the greater effect is on the wetter consistencies, but that the wearing qualities of the drier consistencies is doubled by proper curing conditions during first 21 days.

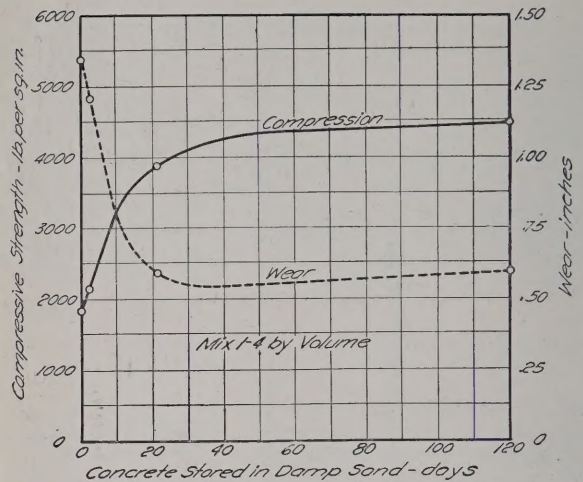


Fig. 12. Effect of Proper Protection During the Early Hardening Period Upon the Compressive Strength and Resistance to Wear of Concrete

Note that these curves are practically the opposite of each other, viz., the resistance to wear decreases, as the compressive strength increases.

warmth and the presence of moisture, especially the latter. The tests show a nearly constant rate of increase in compressive strength and resistance to wear during the first 21 days of proper protection, after which the rate of increase gradually falls off. In deciding on the length of time that a pavement, or other structure, shall be kept covered and moist, it is simply a matter of deciding how much of the potential strength and wear resistance it is desirable to throw away, and reducing the 21 day period by that amount.

There are several methods of protecting concrete pavements and floors during the early hardening period, the most effective of which is the ponding method, and where the grades and other conditions will permit this method to be used, it will give the best results. The protection of concrete structures other than pavements is very often either neglected altogether or at best only half carried out. Many times the leaving on of the forms is considered to be sufficient protection in itself, but this is not so. The forms and all exposed surfaces should be kept thoroughly wet, or at least very moist, continuously for not less than 14 days, and whenever possible for 21 days or more.

Conclusion

Some of the more important developments resulting from the studies at the laboratory have been outlined herein, with two objects in view: First, to bring out the advisability of designing each concrete mixture to produce a concrete of a certain desired strength, with the particular ingredients available, and, second, to call attention to, and emphasize the important features in the making of good concrete.

In reviewing the methods to be employed in obtaining good concrete there are two points which stand out above all others, and if these are followed more good will have been done than by following all other refinements put together. The first of these is, that the least amount of mixing water shall be used that will give a workable mix, and not one drop more. The second is: that no matter with what care the ingredients are chosen, proportioned, mixed and placed, a considerable portion of the beneficial results of this care will be nullified unless the concrete is kept moist during the early hardening period.

September, 1921.

TABLE I
Twelve Sieve Tests of Bennett Gravel. Each taken from a car after placement on the shipping tracks.
Season of 1920
% Passing

| Sieve | 5/4 | 5/4 | 5/8 | 5/13 | 5/17 | 6/11 | 6/22 | 6/26 | 7/10 | 7/27 | 8/21 | 9/11 |
|-------|-----|-----|-----|------|------|------|------|------|------|------|------|------|
| 1 1/2 | 100 | 100 | 100 | 100 | 97 | 99 | 100 | 96 | 100 | 100 | 100 | 100 |
| 3/4 | 86 | 84 | 91 | 94 | 87 | 90 | 85 | 74 | 69 | 48 | 69 | 74 |
| 3/8 | 40 | 43 | 40 | 58 | 40 | 28 | 35 | 40 | 24 | 5 | 11 | 12 |
| 1/4 | 6 | 8 | 3 | 7 | 8 | 3 | 10 | 9 | 5 | 1 | 2 | 1 |

Merits of Fine Gravel as Coarse Aggregate in Concrete for Roads

By John M. Braly, Bennett Gravel Co., Spring Lake, N. J.

By "Fine Gravel" is meant one which practically all passes the 1 1/2 inch and is caught by the 3/4 inch sieve. About 90% passes the 1 inch sieve and about 25% lies below the 1/2 inch sieve. Its habitat is New Jersey south of the Raritan River and it is often spoken of as "South Jersey Gravel". It is practically all quartz. It makes the best and cheapest coarse aggregate available for concrete construction over large areas of the State.

In order to illustrate the physical properties of Fine Gravel, Table I is given. This table gives the sieve analysis of 12 samples, each taken from a carload after the car had been placed for shipment on the day designated. The samples were taken during the season of 1920 at the works of the Bennett Gravel Company. The product includes the whole run of the bank between the 1 1/2 and the 3/4 inch sieves. No effort was made to control the intermediate gradings. The samples were secured by taking 1/2 a cubic foot of gravel from three places in each car, one near the middle and one near each end. The three were mixed and 1/2 a cubic foot taken from the mass. The sieve test was made with the 1/2 cubic foot so secured. Each sample was weighed as a whole before sieving. From the weights so obtained the percentage of voids were calculated in the usual manner, but the sample was not dried. The weighing of the test sample usually took place several hours after the sample was taken and it was so done because the material would be at the time in the condition as when going actually into the work.

TABLE II
Average, Maximum and Minimum Percentage Passing Each Sieve

| Sieve | Average | Maximum | Minimum |
|-------|---------|---------|---------|
| 1 1/2 | 99 | 100 | 97 |
| 3/4 | 79 | 94 | 48 |
| 3/8 | 31 | 58 | 5 |
| 1/4 | 5 | 10 | 1 |

Table II gives the maximum, minimum and average per centage passing each sieve from which it will be seen that the grading varied widely.

Table III gives the fineness modulus of each test and the cumulative average for the series, determined according to the method used by Prof. Abrams in work at the Lewis Institute.

Table IV shows nine (9) crushing tests made on sample cubes from a State aid job in the Borough of Rumson in Monmouth County, New Jersey, built in 1919.

Table V shows eighteen (18) tests on cubes from a job in the Borough of Spring Lake, built in 1921.

Table VI shows tests on three (3) cubes made with Fine Gravel and three (3) with Pennington Trap Rock. The Rumson cubes were made on the job. The Spring Lake cubes likewise. The cubes in Table VI were made in the State Laboratory and all cubes were broken there on the dates and at the ages indicated.

The Rumson and Spring Lake roads were concrete base and bituminous top. The gravel and sand for both these jobs came from the Bennett Plant and the methods of preparation as well as the raw material were precisely the same during the years 1916 and 1921 inclusive as they were in 1920 when data for Tables I, II and III were obtained.

After the Spring Lake tests were completed, consultation with the Laboratory developed the idea that perhaps a more uniform strength could be obtained if a portion of

the minus 1/2 inch product were taken out and the necessary changes were made at the plant to limit the minus 1/2 inch to not over 25%. No tests are yet available by which to judge whether any improvement was made, but the plant is now equipped to limit the minus 1/2 inch to 25% or any other desired quantity.

For usual mixtures the bulk of the mortar content exceeds the bulk of the voids in the coarse aggregate unless the voids are thrown out of line by violent fluctuations in the grading.

To control grading between narrow limits costs money and it is to the distinct advantage of fine gravel that the control is much less expensive than crushed aggregates.

Control of grading is really control of void content, or its reciprocal, absolute solid content. Incidentally this is a good place to suggest that if the proportioning were done by weight instead of by measure there would be no particular need to control grading except as to Maxima and Minima.

But so long as proportioning by measured volume of loose materials obtains, it is interesting to know that with fine gravel the fluctuations in grading have so little influence on the void content and the Fineness Modulus that the run of the bank will usually furnish, between the limiting sieves, a product in which the variation of the void content is so small even when the variations in grading are very great, that the bulk of the mortar always exceeds the bulk of the voids in the coarse aggregate. See Tables I, II and III.

The significance of this fact is of much importance. It means that the actual handling of fine gravel from plant to job leaves it in such condition when used that any tendency it may have to segregate can be ignored and

TABLE III
Fineness Modulus—Weight Per Cubic Foot and Percentage of Voids in Fine Gravel

| Date | Fineness Modulus | Weight per Cubic Foot | Percentage of Voids |
|----------|------------------|-----------------------|---------------------|
| 1920 | | | |
| May 4 | 6.68 | 98 | 41.1 |
| 4 | 6.65 | 102 | 38.0 |
| 8 | 6.66 | 99 | 40.0 |
| 13 | 6.41 | 104 | 36.9 |
| 17 | 6.58 | 99 | 40.0 |
| June 11 | 6.80 | 102 | 37.2 |
| 22 | 6.70 | 97 | 41.0 |
| 26 | 6.81 | 100 | 39.4 |
| July 10 | 7.02 | 101 | 38.6 |
| 27 | 7.46 | 98 | 40.6 |
| Aug. 21 | 7.18 | 103 | 37.5 |
| Sept. 11 | 7.13 | 105 | 36.4 |

that any extra expense incurred in the effort to reform the grading is not justified by the results obtained.

Tables IV and V support the statement. The fine gravel used in both these jobs was precisely the same product as that from which the samples were taken to produce Tables I, II and III. The average strength accomplished with 1:3:5 concrete at 28 days averaged 3391 pounds per square inch, and 1:2:4 at the same age averaged 4733 pounds per square inch.

Since anything over 2000 pounds per square inch is abundantly sufficient for the purpose (base for bituminous pavement) it is clearly good business to use fine gravel whenever and wherever its cost is equal to or less than any other aggregate.

TABLE IV
Six Inch Concrete Cubes—Rumson Road
Proportions 1:2:4

| Cube | Made-1919 | Age | Crushing Loads in lbs. per sq. in. |
|---------------------|-----------|-----|---------------------------------------|
| 1 | 4-14-19 | 7 | 3750 |
| 2 | 4-14-19 | 7 | 3670 |
| 3 | 4-14-19 | 7 | 3760 |
| 4 | 4-13-19 | 28 | 4980 |
| 5 | 4-13-19 | 28 | 4700 |
| 6 | 4-13-19 | 28 | 4580 |
| 7 | 5-26-19 | 7 | 2673 |
| 8 | 5-26-19 | 7 | 2900 |
| 9 | 5-26-19 | 7 | 2645 |
| Average of 7 days— | | | 3233 |
| Average of 28 days— | | | 4753 |

Table VI is the nearest we have to a comparison of fine gravel with broken stone. The tests are limited to three cubes of each and the mixture is different. Different sands were used as well as different cements.

The value of the comparison then amounts to this, that fine gravel is not inferior to trap rock as coarse aggregate. The ultimate strength of these six cubes was probably influenced more by the character of the mortar than by the mineral of the coarse aggregate but it will be interesting to know that the mortar was strong enough to shear some of the coarse aggregate in both sets of cubes, and that the shearing was about the same in both sets.

The discussion so far has been confined to concrete used as a base. What about single course concrete with surface exposed to traffic?

Table VII shows a number of pavements of this type with the years of construction, all using Fine Gravel. The Belmar, Red Bank and Bridgeton Pavements were constructed with gravel from Bennett's, none of them specially prepared but using the regular standard product of the plant as set forth in Table I.

The abrasive resistance has been excellent. In general, the abrasive resistance will depend more on the mortar than on the coarse aggregate. This is because in the con-

TABLE V
Six Inch Concrete Cubes From Ocean Avenue,
Spring Lake, N. J.
Proportions 1:3:5

| Cube | Made-1921 | Age | Crushing Loads in lbs. per sq. in. |
|--------------|-----------|-----|---------------------------------------|
| 1 | 4-21-21 | 28 | 2773 |
| 2 | 4-26-21 | 28 | 2742 |
| 3 | 5- 7-21 | 28 | 3284 |
| 4 | 5- 9-21 | 28 | 3608 |
| 5 | 5-20-21 | 28 | 4150 |
| 6 | 5-25-21 | 28 | 3582 |
| 7 | 5-27-21 | 28 | 3764 |
| 8 | 5-28-21 | 28 | 3153 |
| 9 | 6- 1-21 | 28 | 4673 |
| 10 | 6- 2-21 | 28 | 4363 |
| 11 | 6- 3-21 | 33 | 3478 |
| 12 | 6- 7-21 | 29 | 2300 |
| 13 | 6- 8-21 | 28 | 3810 |
| 14 | 6- 9-21 | 28 | 3362 |
| 15 | 6-10-21 | 28 | 2325 |
| 16 | 6-11-21 | 28 | 3782 |
| 17 | 6-14-21 | 28 | 3419 |
| 18 | 6-16-21 | 28 | 2469 |
| Average 3391 | | | |

struction activity the coarse aggregate is mostly forced down and away from the surface so that the first wear from the traffic comes on the mortar. The fine aggregate and the cement are of far greater importance in resisting abrasion than the coarse aggregate until such time as the top has been worn away until the coarse aggregate has been exposed. When that time arrives (and it will certainly arrive) it will be of great value to the pavement if the coarse aggregate is composed of a mineral of equal hardness and coefficient of wear as the grains of the fine aggregate; for then will the wear act on the coarse aggregate and the surrounding mortar with equal speed and the pavement will continue to present an even surface the same as when it was new and may

TABLE VI
Concrete Cubes
Broken May 12, 1919—Age 28 days

| No. | Mix | Sand | Co'se Agg'gate | Cement | Loads in lbs per sq. in. |
|---------------------|-------|-----------|----------------|--------|-----------------------------|
| 1 | 1:2:4 | Bennett | Fine Gravel | Dragon | 4980 |
| 2 | 1:2:4 | Bennett | Fine Gravel | Dragon | 4700 |
| 3 | 1:2:4 | Bennett | Fine Gravel | Dragon | 4580 |
| 4 | 1:2:3 | Tullytown | Trap Rock | Atlas | 4610 |
| 5 | 1:2:3 | Tullytown | Trap Rock | Atlas | 4650 |
| 6 | 1:2:3 | Tullytown | Trap Rock | Atlas | 4600 |
| Average 1, 2 and 3— | | | | | 4753 |
| Average 4, 5 and 6— | | | | | 4617 |

thus be kept in service until the last available sixteenth of an inch of the wearing portion has been used up.

On the contrary, note what will happen if the coarse aggregate is of a different degree of hardness than the fine. If softer, holes or depressions will begin to appear and maintenance to climb up. If harder, then the mortar will begin to wear away from around the larger pieces leaving them projecting above the surface, as islands of cussedness for which there has not yet been a remedy discovered.

Now practically all the sand available in New Jersey is of silica. Fine Gravel is of silica. Q. E. D.

The advantage of equal abrasive resistance possessed by fine gravel is not due to its size but to the fact that it is all quartz. Coarse gravel is mostly of glacial origin and contains rocks of every kind and degree of hardness, from

TABLE VII
Concrete Roads and Streets
Built With Fine Gravel

| Name and Location of Road or Street | Miles | sq yds | Y'r |
|---|------------|--------|------|
| 1 East Commerce Street, Bridgeton | | 3,400 | 1915 |
| 2 Adelphia, Freehold Road | 1.00 | | 1916 |
| 3 White Street, Red Bank | | 2,671 | 1916 |
| 4 F. Street, Belmar | | 15,000 | 1917 |
| 5 Water Street, Bridgeton | | 2,400 | 1918 |
| 6 South Laurel Street, Bridgeton | | 7,000 | 1919 |
| 7 Pennsgrove-Pennsville, 2d Sec. | 0.886 | | 1919 |
| 8 Bridge Avenue, Red Bank | | 3,740 | 1920 |
| 9 Pennsgrove-Pennsville, 3d Sec. | 1.080 | | 1920 |
| 10 Malaga-Pennsgrove, 4th Sec. | See No. 13 | | 1920 |
| 11 Salem-Pennsville | 0.975 | | 1921 |
| 12 Pennsgrove-Pennsville, 4th Sec. | 1.364 | | 1921 |
| 13 Malaga-Pennsgrove, 5th Sec. | 3.700 | | 1921 |
| 14 State Highway Route 6, Sec. 7 Woodstown-Salem | 3.987 | | 1921 |

slate to basalt. Also, most of the deposits contain so much oversize that the operation of preparing the gravel is about as much a crusher proposition as it is a gravel one with corresponding forfeiture of certain merits set forth above.

To sum up then we have shown—

- That fine gravel makes concrete of strength equal to or superior to other aggregates.
- That it is plentiful in certain portions of the state.
- That the grading to obtain desired density is easily controlled and that even when not controlled at all, it has produced satisfactory results.
- That its abrasive coefficient is correct for use with Jersey Sand and superior to anything yet offered for coarse aggregate in concrete surface type pavements.

We may safely conclude then, that by permitting fine gravel to compete on equal terms with other aggregates offered

- The best interests of the tax payers will be conserved.
- The available tonnage of road metal will be vastly increased.
- Transportation costs will be reduced and freight delays minimized.
- The quality of the pavements, especially the concrete surface type will be raised to the highest possible degree.

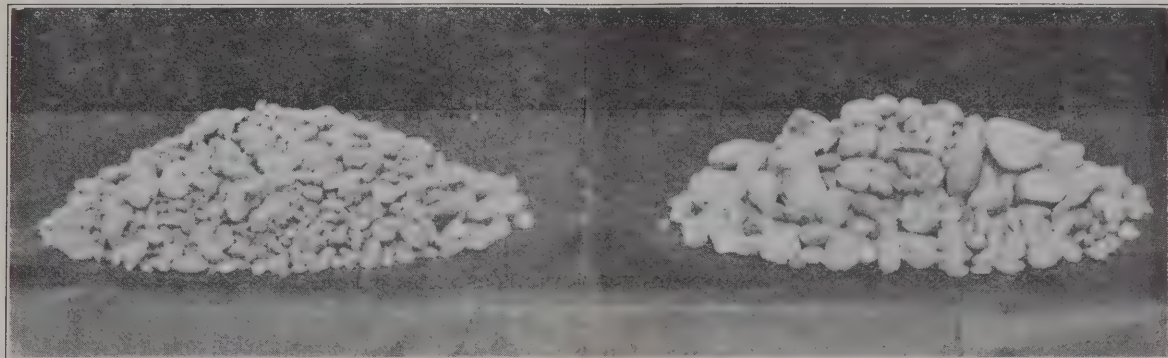


Figure A—South Jersey Gravel. Left, grades same as sample 5-13 in Mr. Braly's Table I. Right, graded same as sample 7-27 in table referred to

Discussion of Mr. Braly's Paper

By Mr. J. G. Bragg, Senior Testing Engineer, New Jersey State Highway Department

Mr. Braly has presented a strong plea for the use of fine gravel aggregate and has shown that it does possess certain merits, chief of which are its plentifulness in portions of our State, the use of which will increase the available tonnage of road metal, and in some cases reduce transportation costs and minimize freight delays. He has, however, undertaken to endow his material with certain merits which it cannot possibly possess.

First, let us consider what is generally accepted as an ideal concrete. Theoretically, we would start with a coarse aggregate, the largest size being not greater than one-third of the distance between reinforcing members or the smallest section to be filled with concrete. The voids in this stone are filled with the next largest size and this is continued until we have reached the smallest particles of sand, after which all remaining voids are filled and all particles of coarse and fine aggregates are coated with cement.

It must be remembered that in addition to the ingredients above mentioned, there is a fourth factor to be considered; namely, water. Add to the above just sufficient water to produce a workable mix and *no more*. The ultimate strength obtained is directly dependent upon this very important ingredient.

Now assuming a coarse and fine aggregate of exactly the same physical properties held firmly together by cement which has the same resistance to stress as the above mentioned aggregates, we have an absolutely homogeneous mass, uniform in character throughout. There are many ways by which we may attempt to attain this ideal, a few of which are—determination of voids, density of trial mixtures, gradation of aggregates, fineness modulus and surface area.

None of these methods produce the desired effect, yet they are all based upon correct assumptions. Many factors make the ideal concrete impossible of attainment, most of which have to do with construction details. Now, while the use of very large aggregate produces strong concrete, there is a practical limit on the size which may be used without undue segregation of the mortar and coarse aggregate. The fact that stronger concretes are obtained by the use of large aggregates has produced a growing tendency toward too large an aggregate. The upper limit on size, however, does not stop at one (1) inch merely because ninety (90) per cent of our South Jersey gravel is smaller than that, and we are no more justified in adopting generally an excessively fine aggregate that we are to go to extremes on large aggregates. If we do either, the producers of materials are to be congratulated upon their ability to crack jokes at the expense of the Engineering profession.

Mr. Braly makes the statement that to control grading between certain limits costs money. We do not dispute this fact; neither can there be any question of the value received for money thus expended. The control of grading between certain limits means more than the control of void content only. It controls also the accumulative surface area of coarse aggregate to be held together with a

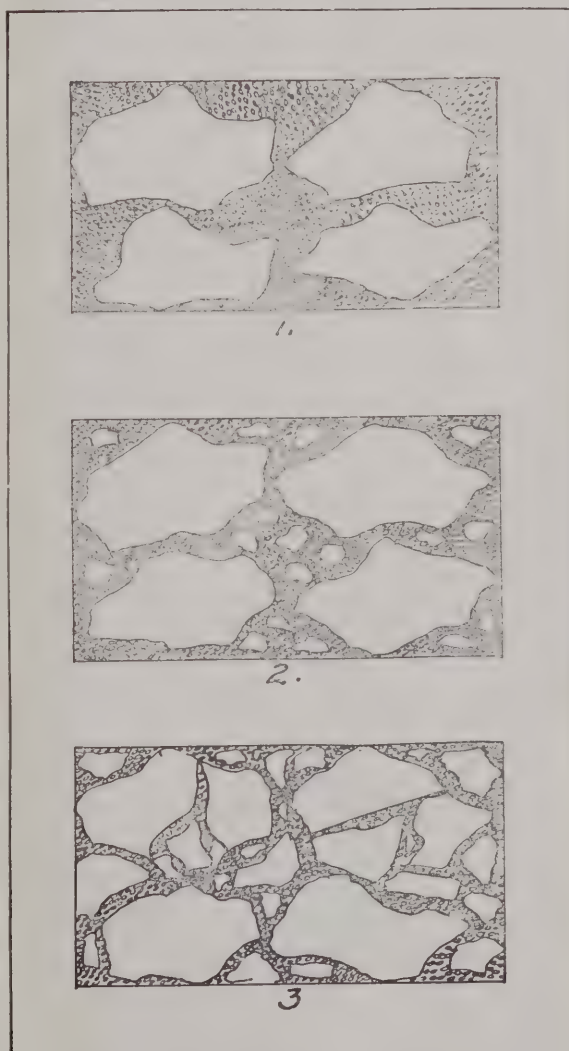


Figure B—Character of concretes obtained with various gradings

1. Coarse aggregate, all one size
2. Poorly graded aggregate, showing effect of "robbing". Large and small particles of coarse aggregate with no intermediate sizes.
3. Properly graded from largest to smallest particles

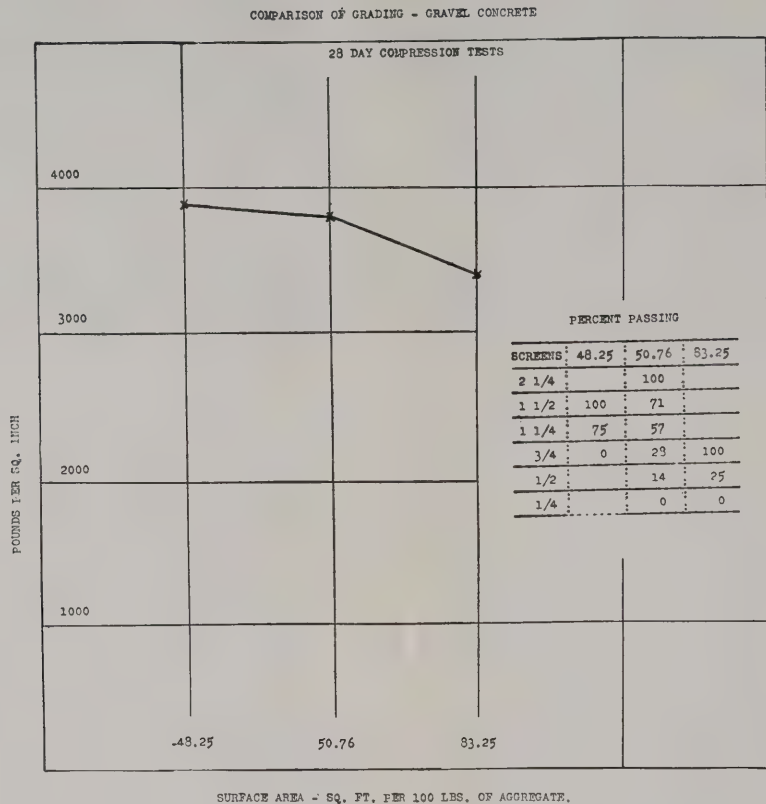


Figure C—Shows decrease in strength with increase in surface area of coarse aggregate

unit quantity of cement, and since any change in surface area makes necessary a change in the amount of water used, grading control aids in the production of a concrete having the very important element of uniformity.

Without proper control of grading it is practically impossible to specify proportions in any manner which will result in a concrete of generally satisfactory quality. The differences in grading as shown in Mr. Braly's tables produces differences in void content sufficiently large to change his actual proportions from the specified 1:2½:5 to 1:3:5. The surface area of his material varies from 56 to 106 square feet per 100 pounds.

TABLE NO. 1

Variations in Cement Content Due to Variations in Per Cent Voids.

Mr. Braly's Table III shows variations of approximately 5%.

Proportions 1:3:5

| Per Cent Voids | Bags Cement Per Cu. Yd. | Shortage in 6 Inch Slab 50 Feet Long |
|----------------|-------------------------|--------------------------------------|
| 40 | 4.44 | |
| 35 | 4.24 | 4 Bags |

TABLE NO. 2

Change in Proportions to Allow For 5% Variations In Voids.

| Per Cent Voids | Specified Cement Content | Proportions | Actual Cement Content Per Cu. Yd. |
|----------------|--------------------------|-------------|-----------------------------------|
| 40 | 4.44 | 1:3:5 | 4.44 |
| 35 | | 1:2½:5 | 4.52 |
| | | 1:3:4½ | 4.52 |

TABLE NO. 3
Surface Area Comparison
Of Gravels From Mr. Braly's Table I.

| Sample | Per Cent Voids | Surface Area Per 100 Pounds Of Aggregate |
|--------|----------------|--|
| 5/13 | 36.9 | 106.12 |
| 7/27 | 40.6 | 56.22 |

Time is not available to go into detail relative to the strengths secured with the use of fine gravel. It can be said, however, that when properly proportioned and properly prepared, satisfactory strengths are obtained. Mr. Braly has made certain statements, relative to the wear coefficient of South Jersey gravels which warrant the presentation of a few facts. He says in effect that both fine and coarse aggregates should have equal wear resisting properties and since South Jersey gravel and South Jersey sand are both composed of Silica—Q. E. D. As you know, Q. E. D. means "thus it is proven", and we propose to disprove his theory P. D. Q.—which means just what you think it means.

Last winter we made some wear comparisons of sands and gravels from different producers. It is natural to assume that some definite relation would exist between the wearing qualities of gravel and sand from the same deposit. We find, however, that in one deposit, in which the gravel shows eight (8) per cent wear, the sand shows nearly four (4) per cent. In another deposit the gravel shows thirty (30) per cent. wear and the sand less than two (2) per cent. Here we have one gravel showing only one-quarter as much wear as the other, but the sand from that deposit shows nearly twice as much wear as the sand from the second deposit. We find, also, that when made into concrete the strength of both aggregates is highest when the sand showing least wear is used, and lowest when the sand showing the most wear is used. In a general way, it may be said that the wearing quality of concrete is dependent upon its strength properties, that is, a concrete having a high compressive strength will have a relatively high resistance to abrasion.

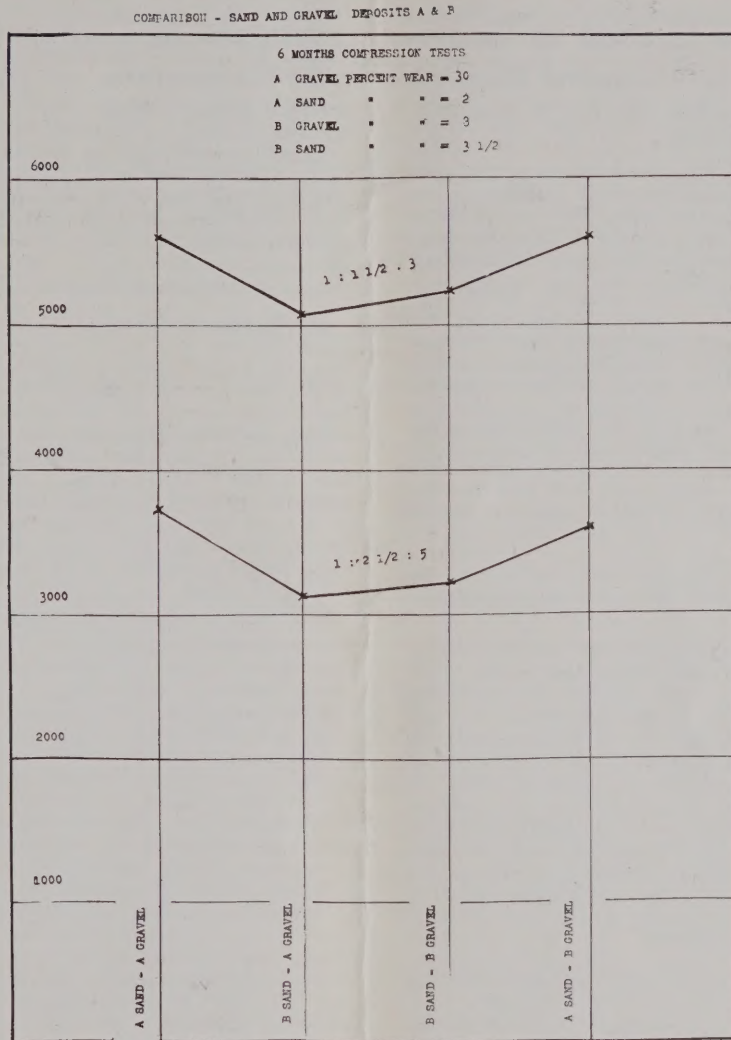


Figure D—Showing strengths obtained with various combinations of sand and gravel from deposits A and B

We can admit then that South Jersey sand and South Jersey gravel are both of Silica composition, but the inference that their use will produce a concrete of uniform wearing qualities is indicative of guess work only.

Some mention is also made of the so-called Islands of Cussedness caused by the use in concrete pavements of a coarse aggregate having a greater degree of hardness than the fine aggregate. We have heard this phase of wear on concrete mentioned before, and perhaps somewhere such a condition exists, but we must all admit the paucity of information directing us to a pavement which shows the action described. No doubt those who have advanced this theory are sincere in their beliefs, but I feel that these Islands of Cussedness are encountered only by those who are at sea with their theories.

It is not meant to imply in this discussion that fine gravel aggregate has no place in the construction of good roads. It can be used to very good advantage in certain localities, but when so used it must be uniformly graded, and some allowance must be made for discrepancies in its potential concrete making value.

I will answer the summations of Mr. Braly's paper as follows: To the statement that "fine gravel makes concrete of strength equal to or superior to other aggregates," I will say that, given other aggregates of the same physical

properties a well graded coarse aggregate is always superior. That fine gravel is plentiful in certain portions of the State is admitted. I will admit also the ease with which the grading can be controlled, but I would state further that the place to control this grading is in the plant of the producer, and it is certain that when grading is not controlled, satisfactory results are very seldom secured in the field. To say that "the abrasive coefficient of South Jersey gravel is correct for use with Jersey sand and superior to anything yet offered as coarse aggregate in concrete surface type pavements" is absurd. It is also absurd to say that "by permitting fine gravel to compete on equal terms with other aggregates offered, the best interests of the tax payers will be observed and the quality of the pavements, especially the concrete surface type, will be raised to the highest possible degree." Such statements are usually made by those who have something to sell and are not based on conservative engineering practice or theory. The best interests of the tax payers are served when we use the best material obtainable which may be procured at a reasonable cost. Now, the fine gravel of South Jersey has been, and no doubt will continue to be, economically employed in the building of our roads; but fine gravels cannot hope to compete on equal terms with better aggregates.

Merits of Fine Gravel as Coarse Aggregate in Concrete for Roads

General Discussion at the Convention

COL. WHITEMORE: There certainly must be some questions on this interesting subject.

MR. CAWLEY: I would like to ask Mr. Bragg a question. In one of the diagrams he shows a change in the grading of the aggregates in getting the same class of concrete in two different ways, one by changing the large aggregate and one by changing the sand. Is there any difference between adding more of the large aggregate or adding more of the sand?

MR. BRAGG: That depends very largely upon the way your concrete works. With a gravel aggregate, similar to Mr. Braly's material, you could probably reduce the sand. What I meant was that, if possible, you should go shy on the sand rather than on the coarse aggregate. Gravel works easier usually than a harsher, more angular aggregate.

MR. CAWLEY: Which will give the strongest test, increasing the sand or the stone?

MR. BRAGG: Decreasing the sand gives higher strength, but you will not always get the most workable mix by this method.

MR. HOWARD: The use of gravel for concrete base or foundation and pavements has been in use for 150 years. Statistics can be consulted and you will find provisions for gravel concretes. You will find that the city of Paris, with its solid streets, Berlin and Geneva, Switzerland, also, all of them use gravel aggregate for foundations of all kinds of pavements. Paris takes its gravel from the Seine. Keep the cement content down to the minimum to keep the particles together. We all recognize that by grading the gravel from the coarses down to the fines, then putting in sand with cement, that you construct a mixture which is plastic, workable, and efficient. In Glasgow they require crushed granite graded with Portland cement, mixed into a solid mass.

MR. GAGE: In further reference to the best method to follow in designing or correcting concrete mixtures, I will state that the impression I received from the papers just read was that the strength and general value of concrete depend much more on the character of the mortar than the aggregate. Such being the case, I would like to ask Mr. Bragg if the strength of concrete in general is not improved more by decreasing the sand content than the stone.

MR. BRAGG: The quality of the concrete is improved by keeping as near as you can to the graded aggregate shown in the chart. A well graded mixture, all the way down from the biggest stone to the smallest particle should not require any change of proportion. If, however, a change is necessary and you merely cut down on the stone you will increase the proportion of mortar and you are bound to decrease the relative strength of your concrete as compared with concrete in which the sand was reduced. If you can secure the cement content by reducing the sand and still have a workable mix, that is the thing to do, but there is a point beyond which you cannot go and retain a workable mix. Not enough mortar to carry your stone will make a harsh working mix. Trying to increase the cement content by reducing the sand only, will sometimes produce a mixture which works very hard, making it very difficult to handle simply due to the fact that you have not enough mortar to slightly more than fill the voids in the coarse aggregate.

MR. BRALY: I would like to ask a question relative to the qualities of sand and gravel which Mr. Bragg mentioned. How does he arrive at the co-efficient of wear?

MR. BRAGG: Practically the same method is used in both cases. The same machine is used in determining the per cent. of wear on gravel as on sand. The methods vary, however, due to the fact that the particles of sand are very much smaller than gravel and the test has to be made on a smaller scale. For determining the per cent of wear on gravel, a sample consisting of certain sizes and weighing

a certain definite amount, is put into a standard De Val abrasion machine. A standard charge of large steel shot is added and the machine is revolved several hundred times. The per cent wear is calculated from the difference in weight due to loss of material passing a 16-mesh sieve. The same method is used on sands except that the shot are smaller, the charge of sand weighs less and the sieves used are much smaller. All sand tests are comparative as are also the gravel tests.

MR. BRALY: That explains it very clearly, and I think I can say that that agrees very much with what I said. However, I may have created the impression that I guessed at the basis for the statement I made that wear between South Jersey gravel and the mortar which surrounds it is entirely uniform. I did not guess at that, and regret very much that I cannot show you photographs, but I can mention to you F Street, Belmar, where the pavement has begun to wear and the whole appearance is just like glass, it is so smooth, so I still stick to what I stated, that I believe it is a fact that coarse aggregate will wear uniformly with the mortar. This is to be determined in actual use in the work.

MR. BRAGG: That is one of the usual statements that the Laboratory has to meet; i. e., laboratory tests are not practical. You do not have to go to Belmar to see the action described by Mr. Braly. We have a sample of concrete in the Laboratory showing exactly the same action, taken from Bellevue Avenue, Hammonton. I do not know how I can explain any clearer what I was getting at. I wanted to show that you cannot say that because sand and gravel come from the same deposit they will have the same wearing qualities. They distinctly do not have and our tests prove it conclusively. There is no way to prove they do have, no matter how tests are made, whether the tests compare with field conditions or whether they are compared among themselves. The sample of concrete which we have in the Laboratory shows exactly what Mr. Braly brought out and also disproves one of the things claimed against gravel aggregate; that it will spall out of the surface. This gravel has not spalled out of the surface although subject to rather severe traffic for five or six years carrying the White Horse Pike traffic to Atlantic City, before the present Route No. 3 was adopted through Hammonton. I was not trying to say that the sand and gravel of Mr. Braly's won't wear, I was trying to say that the mere fact that they are both of silica composition is not an indication of their physical properties. When these aggregates are properly graded and proportioned, a pavement of good wearing qualities should be obtained.

MR. ALDRICH: I would like to ask Mr. Bragg a question relative to spalling out of the surface. I would like to know whether any comparative tests have been made on samples taken from actual jobs as to disintegration or spalling out of the surface because it seems, from the practical standpoint, that the gravel, working a little smoother than broken stone, would probably give you, under practical conditions, a slightly more dense sample.

MR. BRAGG: Our wear tests made on 5 in. x 8 in. x 8 in. specimens of concrete, show no greater spalling for gravel than for stone. Density of the concrete is dependent upon grading, mixing, water and proper tamping and I would not say that either aggregate has the advantage in that respect.

MR. MANSEY: I would like to say for Mr. Braly's benefit, and from observation of the road you speak of, White Street, that I happened to be the builder, and at that time had just built a trap rock road, and had some material left over. I was allowed by the Engineer to build the first block with trap rock with exactly the same mix as the gravel. That was in 1915, and from observations,—one inspection as recently as two or three weeks ago—there has been no difference in the wearing qualities. No cracks have appeared. One is standing up as well as the other.

COL. WHITEMORE: I might refer again to some of my former experience. I believe you have in mind, but did

not state, that it is almost always subject to the wear of rubber tired vehicles. I have seen, with the same identical mixture of gravel, cement, and sand, or stone instead of gravel, that was subjected to the traffic of steel tired vehicles, heavily loaded with material weighing from seven to ten tons on four wheels. The gravel was shoveled out before the end of two years. The concrete with trap rock, up to this summer, when the timber structure, not being creosoted, had to be renewed, was relaid with trap rock. That was one kind of traffic, but it brings out the destructive effect of iron tires, which some States will not permit.

MR. BRALY: What year was that pavement put in?

COL. WHITTEMORE: I think it was somewhere about 1904 or 1905.

MR. BRALY: Was the gravel clean—prepared in a proper plant?

COL. WHITTEMORE: It was commercially clean gravel, brought by scow.

MR. BRALY: The reason I asked was because it sounds like dirty gravel.

MR. GAGE: In further reference to the spalling or weathering of coarse aggregate used in concrete, I would like to refer to the Albany Post Road. It was reported that these holes were caused in this road by the use of a soft limestone, which had shattered or weathered and forced out of the pavement by traffic. Some of these holes were carefully examined by me and it was found that the material that was originally used in these openings was a mica soapstone. The quarry from which the aggregate was secured was then examined and it was found that there was a seam of this soapstone in the quarry which was directly responsible for the holes in the pavement. Many of the concrete roads constructed around Chicago and in Minnesota have these same defects. In this case, they are caused by the gravel containing a soft, unstable slate, which quickly weathers and wears out and cannot be separated from the aggregate except at considerable expense.

The most remarkable thing about these occurrences is, all statements to the contrary, that the edges of the concrete around these small openings have not broken, neither have they in any other way damaged the concrete except from appearance, yet some of these roads have been down from six to eight years.

In regard to the wearing properties of concrete or the aggregates used therein, I believe that we are not justified in the expenditures required to determine this quality of an

aggregate only to a limited extent, for personally I have never seen or do not know of a concrete pavement failing by wearing out, and I have only known of one or two concrete bases where loaded trucks have broken through them. I can't see why we would put so much stress on the wearing properties of concrete when there is very little likelihood of a failure in this respect when there are several other factors that do affect these pavements much more injuriously. If these pavements can be held together so that they will not crack, ravel and go to pieces, I feel perfectly safe in saying that we need not worry about their wearing into ruts or holes.

MR. BRAGG: I have never seen a concrete pavement where the mortar has worn out around the stone. I have seen pitted surfaces because of soft particles in the concrete, however, I would say a concrete pavement will last until it is broken up from other causes and will never wear out.

COL. WHITTEMORE: I have seen wear of traffic in and out of a building, confined to a 12-foot doorway. Most of the loads were going in, carried on steel tired trucks. Standard load was seven tons; the wagon and horses weighed two tons. The traffic was evidenced by a space 12 to 13 inches wide on each side, where the wagon wheels passed, for a length of about four feet inside the doorway and outside. Then the depression, about $\frac{5}{8}$ of an inch, which was due to wear, disappeared because the traffic spread. One of the piers went out of business due to war conditions, and I inspected the site recently. They were cutting out this wheel track with chisels and hand hammers to remove the depression. This was entirely due to steel-tired, heavily loaded trucks, and, since they are practically non-existent at present, I do not think you will find much wear due to localized traffic, if other conditions are kept from being the destroying factors.

MR. MOORE: Mr. Braly made a statement of the wear as shown on a Belmar pavement where his product was used. I would like to know if he has any reliable information as to what depth it is wearing. The statement was made to me that that surface is wearing considerably, that during the last 5 or 6 years the entire surface has worn, in some places to the extent that the reinforcement is showing. Are there any reliable measurements to show if the wear is to that extent?

MR. BRALY: No. The sand used was rather fine, which did not make the best mortar. The north end was built with materials from another plant, where not always the best results were obtained in washing. When speaking of it, I referred to the portion built with properly washed material, and would say that on the south end, where proper materials were used, there is practically no wear.





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